Claims

1. (Currently amended) A mixed-mode fuel injector comprising:

(i) a nozzle body (5) including a tip, comprising a passage for fuel (FP) which includes an inner cylindrical space for receiving a needle valve (1), and an inner conical surface (C) at the tip (7) of the nozzle body, the conical surface guiding a spray of fuel;

(ii) the needle valve (1) having a converging-diverging conical head wherein the head diverges at its upstream end and converges at its downstream most end for guiding a spray of fuel, the needle valve including a conical seal surface upstream of the head; wherein the needle valve being moveable between open and closed positions by a driving means within the nozzle body, wherein in the closed position the sealing surface of the needle valve is pressed against nozzle body (5) to block fuel flow, and in the open position the needle valve seal surface being lifted away from nozzle body to permit fuel flow, and

(iii) a micro-variable-circular-orifice comprising a variable annular ring aperture (4) between the needle valve and the nozzle body for producing a hollow conical spray, and between 1 and 20 multijet-orifice (6) distributed *underneath* the conical surface (C) as *closed* channels each for producing a jet spray, such that fuel is discharged in variable spray patterns of hollow conical and multiple jets through the micro-variable-circular-orifice by lifting the needle valve to different positions, with hollow conical spray pattern being produced first followed by multiple jet spray patterns.

2. (Currently amended) A mixed-mode fuel injector comprising:

(i) a nozzle body (5) including a tip, comprising a passage for fuel (FP) which includes an inner cylindrical space for receiving a needle valve (1), and an inner conical surface (C) at the tip (7) of the nozzle body, the conical surface guiding a spray of fuel;

(ii) the needle valve (1) having a converging-diverging conical head wherein the head diverges at its upstream end and converges at its downstream most end for guiding a spray of fuel, the needle valve including a conical seal surface upstream of the head; wherein the needle valve being moveable between open and closed positions by a driving means within the nozzle body, wherein in the closed position the sealing surface of the needle valve is pressed against nozzle body (5) to block fuel flow, and in the open position the needle valve seal surface being lifted away from nozzle body to permit fuel flow, and

(iii) a micro-variable-circular-orifice comprising a variable annular ring aperture (4) between the needle valve and the nozzle body for producing a hollow conical spray, and between 4 and 20 multijet-orifice (6) distributed on the conical surface (C) as open channels each for producing a jet spray, such that fuel is discharged in variable spray patterns of hollow conical and multiple jets through the micro-variable-circular-orifice by lifting the needle valve to different positions, wherein the maximum needle lift for the opening position is in the range of 1-300

micrometers, the needle head diameter at its widest portion is in the range of 0.8-3.5mm, and the angle between a centerline of the nozzle body (5) and the inner conical surface (C) at the nozzle body tip (7) is approximately in the range of 35-75 degree.

3. (Currently amended) A mixed-mode fuel injector according to claim 1, wherein the conical surface (C) has a single conical surface.

4. (Currently amended) A mixed-mode fuel injector according to claim 1, wherein the conical surface (C) is an integrated conical surface having two or more conical surfaces with different conical angles connected together.

5. (Currently amended) A mixed-mode fuel injector according to claim 1, wherein the conical surface (C) is a diverging curved surface.

6. (Currently amended) A mixed-mode fuel injector according to claim 1, wherein the needle lift for the opening position is approximately in the range of 0-300μm, the needle head diameter is approximately in the range of 0.8-3.5mm, and the angle between the centerline of the nozzle body (5) and the inner conical surface (C) at the nozzle body tip (7) is approximately in the range of 35-75 degree.

7. (Previously presented) A mixed-mode fuel injector according to claim 2, wherein the plurality of multijet-orifices (6) is on the said conical surface (C) with cross sections that are one or more of semi-circles, arcs, triangles, trapezoids or other polygons.

8. (Currently amended) A mixed-mode fuel injector according to claim 1, wherein the needle head (3) remains at least partially received within the tip (7) as the needle valve (1) is moved back and forth between the biased closing position and opening position such that when fuel is injected through the micro variable aperture (4) between the needle head and said conical surface (C) of the nozzle body, fuel is also injected through the multijet-orifices *(6)*, the upper surface of the needle head and the conical surface (C) serve as guiding surfaces for fuel sprays.

9. (Previously presented) A mixed-mode fuel injector according to claim 7, wherein there are about 4-20 multijet-orifices with the cross-section of semi-circles with the diameters approximately in the range of 50-300μm.

10. (Previously presented) A mixed-mode fuel injector according to claim 7, wherein there are about 4-20 multijet-orifices (6) having a cross-section other than semi-circles with the maximum dimension approximately between 50-400μm.

11. (Currently amended) A mixed-mode fuel injector according to any of *claims 1*, wherein the sizes of said multijet-orifices (6) are the same.

12. (Currently amended) A mixed-mode fuel injector according to any of *claims 1*, wherein the sizes of the multijet-orifices (6) are different depending on specific needs of atomization.

13. (Cancelled) A mixed-mode fuel injector according to *claim 2*, wherein the said multijet-orifices (6) are distributed on or under the conical surface (C) so that they can be open channels or closed channels.

14. (Currently amended) A mixed-mode fuel injector according to claim 1, has a plurality of multijet-orifices underneath the said conical surface (C), forming a sac-hole or valve-covered-orifice multi-hole type injector through blocking the circular aperture by the needle head at a predefined needle-lift range.

15. (Currently amended) A mixed-mode fuel injector according to claim 1, wherein different shapes of fuel sprays are generated by changing the magnitude of lift of said needle valve (1) and the needle valve is arranged within the nozzle body (5) so that, at low to medium injection loads, fuel is mainly injected through the variable circular aperture between the needle head (3) and_conical surface (C) of nozzle body (5) by a small needle lift, thus mainly forms a conical shape spray, while at high injection loads, fuel is injected through both the variable circular aperture (4) between the needle head and nozzle body and the multijet-orifices (6) by a larger needle lift, thus forms a mixed-mode conical-multi-jet shape spray, whereby provides different atomization desired by engine combustion at different loads.

16. (Currently amended) A mixed-mode fuel injector according to claim 1, wherein different shapes of fuel sprays are generated by changing the magnitude of lift of said needle valve (1) and the needle valve is arranged within the nozzle body (5) so that, at low to medium injection loads, fuel is mainly injected through the variable circular aperture (4) between the needle head (3) and conical surface (C) of nozzle body by a small needle lift, thus mainly forms a conical shape spray, while at high injection loads, the needle head can completely or partially block the variable circular aperture by a large needle lift, whereby fuel is fully or mainly injected

through the multijet-orifices (6), thus mainly forms conventional multi-jet sprays at high loads, whereby provides different penetration desired by engine combustion at different loads.

17. (Cancelled) A mixed-mode fuel injector according to claim 1 or 2, wherein the fuel channel between the needle valve (1) and the nozzle body (5) is of converging-diverging shape and by lifting said needle valve at different magnitudes, the minimum cross-section is at the sealing surface (2) during the early stage of fuel injection, the minimum cross- section is at said micro-variable-circular-orifice or at the sealing surface (2) during the middle stage of fuel injection, and the minimum cross-section is at the sealing surface (2) again during the late stage of fuel injection, whereby it has means of ensuring fine atomization during all fuel injection stages.

18. (Currently amended) A mixed-mode fuel injector according to claim 1, wherein the angle between the centerline of the conical surface (C) and the centerline of the nozzle body (5) is approximately 0-15 degrees, depending on an angle between a centerline of the fuel injector and a centerline of a piston in an engine cylinder.

19. (Cancelled) A mixed-mode fuel injector according to any of the preceding claims, wherein the fuel injected is one or more of diesel fuels, gasoline fuels, alternative fuels, mixtures of water and fuels, pure water or liquid exhaust cleaning additives wherein the fuel injector is a general purpose injector.

20. (Cancelled) A mixed-mode fuel injector according to claim 1, wherein the needle valve (1) is passively driven by high fuel pressure which provides said driving means.

21. (Cancelled) A mixed-mode fuel injector according to claim 1, wherein the needle valve (1) is actively driven by an actuator which provides said driving means.

22. (Cancelled) A mixed-mode fuel injector according to claim 21, wherein the actuator is a solenoid or a piezo actuator.

23. (Cancelled) A mixed-mode fuel injector, which has a micro-variable-circular-orifice (MVCO) comprising a variable annular ring aperture as in claim 1, wherein the MVCO is used as a sole orifice or in-combination with other multi-hole conventional orifice wherein fuel is injected through multiple channels in multi-jets into combustion chamber.